CORE RESIDUE, TILLAGE, AND ROW SPACING EFFECTS ON SOYBEAN

BY

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THESIS

Submitted in partial fulfillment of the requirements
for the degree of Master of Science in Crop Sciences
in the Graduate College of the
University of Illinois at Urbana-Champaign, 2014

Urbana, Illinois

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ABSTRACT

Most soybeans [*Glycine max* (L.) Merr.] follow corn (*Zea mays* L.) in the US corn belt, and soybean seed is often planted without tillage into standing corn residue or, if tilled, into a considerable amount of corn residue left on or near the surface. The increase in corn residue with increasing corn yields raises the question about whether corn residue interacts with tillage to affect soybean yields. During 2012 and 2013, corn residue was left standing, chopped, or removed, followed by tillage or no-till before soybean planting. In addition, row spacings of 38 or 76 cm and effect of foliar fungicide were evaluated within residue-tillage treatments. Across two years at Urbana, yield response to combinations of row spacing and tillage responded similarly in standing and chopped residue treatments but were different when residue was removed. There were no significant differences due to treatment across the three southern Illinois sites, but at Dixon Springs in 2013, 38-cm rows yielded more than 76-cm rows, and across residue treatments, tillage with fungicide yielded more than tillage without fungicide, and at Brownstown in 2012, soybeans in standing corn residue yielded 199 kg ha^{-1} more than those without corn residue. Nodule numbers at Urbana in 2013 were higher in the standing corn residue treatment compared to the chopped and removed residue treatments at R6. While these results show rather modest and inconsistent responses of soybean yield to management of corn residue from the previous crop, they do indicate that tilled soybeans had higher yields in Urbana, the northernmost environment with more productive soils, but in the southern environments with less productive soils, soybean yield did not respond to tillage treatment.

ACKNOWLEDGEMENTS

I would first like to thank Dr. Emerson Nafziger for serving as my advisor. I would also like to extend my gratefulness to my committee members Drs. Dean Riechers and D.K. Lee. I would like to thank my fellow graduate students, Joshua Vonk and Jacob Vossenkemper, for their support and encouragement. My parents deserve a special thank you for continually supporting and encouraging me along the way. My husband Kyle Corder deserves many thanks for his endless encouragement, positivity, and confidence in me. Finally, I would like to thank God for giving me the strength and endurance to pursue and complete an advanced degree.

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INTRODUCTION

Corn residue, tillage, and row spacing are three factors that can affect soybean production. Although each factor has been studied individually, there are few studies that examine the combination of these factors. Corn residue is an important factor in the management of soybean production in corn-soybean production systems. In southern Illinois, it is common for soybeans to be planted into standing corn residue without tillage. While there have been a number of studies examining how corn residue affects soil properties (Stetson et al., 2012; Karlen, 2011; Laird and Chang, 2013), few studies been done to investigate effects of corn residue on soybean yield.

The effects of tillage and row spacing on soybean yields have been studied more thoroughly. Yield responses to tillage are mixed and sometimes complicated by pest issues (Temperly and Borges, 2006). Narrower rows provide more equidistant spacing between plants than the conventional 76-cm rows; this means less competition for water and nutrients (Zhou et al., 2011). Some producers use foliar fungicide treatments to reduce production risks (Swoboda and Pedersen, 2009). Strobilurin fungicides have been shown to produce some physiological changes such as delayed leaf senescence, increased water use efficiency, and increased leaf area duration (Grossman et al., 1999; Grossmann and Retzlaff, 1997). A foliar fungicide/insecticide treatment was included to examine how a fungicide/insecticide treatment could interact with the other factors.

The objectives of this study were to test, in different soils and weather conditions, the effects of corn residue management, tillage, row spacing, and fungicide/insecticide on soybean grain yield, plant density, and plant height, and to test the effects of corn residue management and tillage on soybean root nodule counts.

LITERATURE REVIEW

Residue

Many studies have focused on the effects of corn residue on the soil, but even with most soybeans in the US Corn Belt following corn in rotation, there has been little research into corn residue effects on soybean production. Doran et al. (1984) established that soybeans yielded 24% less when sorghum residues were removed than when residue was left on the soil surface. They examined grain yields with 0, 50, 100, and 150% of the previous crops' residues on the soil surface using a corn, sorghum, soybean rotation under no-till. This yield reduction with residue removal is due to low content of available soil water, high soil temperatures on the surface, and poor canopy development.

Soybean yields under deficit irrigation were increased by residue of either corn or soybean compared to bare soil (van Donk et al., 2012). Bare soil plots tended to dry faster, but they also had bigger soybean plants at the beginning of the growing season. In 2009, soybeans grown in corn residue-covered plots yielded 0.6 Mg ha^{-1} more than soybeans grown in bare-soil plots. The residue-covered plots had 90 mm more available water than the bare soil plots. In 2010, soybeans grown in soybean residue-covered plots yielded 0.5 Mg ha^{-1} more than their counterparts in bare-soil plots. The soil water content of the residue-covered plots and the bare soil plots were not different. Soybeans grown under deficit irrigation in corn residue-covered plots had higher yields, likely because of the increased available water compared to bare soil plots.

Soybean yields are affected by corn residue removal (Meki et al., 2013). In five Midwestern states, soybean yield was examined using the Agricultural Policy Environmental Extender (APEX) model, because this model encompasses many site specific factors that affect how corn residue removal would affect soybean grain yield. This model was simulated for 47 years. Soybean yields were evaluated with four rates of corn residue removal - 0, 40, 60, and 80% in 3,703 farm fields in the Upper Mississippi River Basin. Soils were classified into three textural classes and four hydrologic groups. Residue removal, management practices, land type, soil textural class, and soil hydrologic group affected soybean grain yield. When residue was not removed, soybeans yielded 2.4 Mg ha^{-1}, but when 40, 60, and 80% of residue was removed, soybeans yielded 2.2 Mg ha^{-1}, or 8% less. Sandy soils had lower yields than clayey and loamy soils. Land erodibility classes were similar. Along with a 6% reduction in annual soybean N fixation with corn residue removal, annual soil organic N storage also decreased 5%.

Soybeans tended to yield more following corn with corn residue present than without corn residue present, but when soybeans followed soybeans, yields tended to be higher without corn residue present (Crookston and Kurle, 1989). Eight cropping situations were studied – all combinations of the corn-soybean rotation with or without corn residue on the soil surface. The previous crop, either corn or soybean, was the main plot and residue treatment - no residue adjustment, corn residue removed, or corn residue added - was the subplot. Averaged across years and locations, there was no difference in soybean yield in soybean following corn with or without corn residue present. At one year and location of the study, corn residue presence reduced soybean yields. Since this yield response to corn residue was not consistent across previous crops, the authors concluded that the interaction of previous crop and corn residue confirms that yield response to residue is not a consistent response.

Tillage

In a Plano silt loam, soybean grain yields were higher with no-till than conventional tillage in soybean following corn but not in continuous soybeans (Temperly and Borges, 2006). First year soybeans following five years of corn yielded 4.00 Mg ha^{-1} in the no-tillage system but only 3.01 Mg ha^{-1} in the conventional tillage system. Soybeans in the no-tillage system yielded more in all rotations except for continuous soybean. The authors noted that the findings of this study agree with one study also conducted at the same site, but disagree with other studies at the same site. SCN was found in this study in 2001, and soil testing for SCN showed more SCN in the conventional tillage system than in the no-tillage system. SCN egg population was negatively correlated with grain yield, but the SCN covariate was not significant for grain yield. Because of this, the SCN infestation did not explain the low yields in conventionally tilled soybeans.

In a tile drained Nicollet-Webster clay loam soil complex in Minnesota, few differences occurred in soybean yields due to tillage treatments (Vetsch et al., 2007). Eighteen treatments were used which included a variety of tillage systems for corn following soybean and soybean following corn. In 2000, soybean yields were 0.24 Mg ha^{-1} higher with the chisel plow + spring field cultivation tillage treatment compared to the no-tillage treatment, but for the remaining two years, tillage treatments did not result in significantly different soybean yields. May of 2000 had 59 mm more precipitation than normal and June had 108 mm more precipitation than normal. Lower yields in no-till compared to chisel plow + spring field cultivation in 2000 were possibly due to the wetter than normal spring.

Soybean yields on a Chalmers silty clay loam in no-till were 8% lower in rotation and 5% lower in continuous soybean compared to plowing when averaged over the 20 years of this study (West et al., 1996). Rotated soybeans grown under no-till had 11.6% lower populations than their counterparts in plowed treatments; this could be because of higher variability in seeding depth or possible seedling disease. Lower yields in no-till soybeans may have been because of brown stem rot, which has been a problem for no-till soybeans in Wisconsin before, although no differences in infection were seen in this study. Additionally, no-till soybeans yielded more than the other tillage systems in 1991 when a drought started midsummer, but in 1988 when a drought started in May, no-till soybeans in rotation had lower yields than those in continuous cropping. It is possible that soybeans were unable to respond to the extra available soil moisture when the drought started in May, but when a drought started midsummer, soybeans may have been more able to establish rooting systems and thus more able to take advantage of soil moisture.

Tillage had no effect on the stand or yield of soybeans (Turman et al., 1995). In soybean following corn planted in a Tiptonville silt loam, tillage treatments - no-tillage, ridge tillage, and conventional tillage – had no effect on stands or yield. There may not have been a difference in soil temperature between the tillage treatments, and because of this, no differences in soybean stand or yield were observed.

In central Iowa in glacial till soils in a corn-soybean rotation, Karlen et al. (2013) found that soybean yields were highest in the moldboard plow and no-till treatments and lowest in the spring-disk tillage treatment. In both the middle and end phases of the 30 year study, the moldboard plow and no-till had the highest soybean yields, while spring disk had the lowest yields. Soybean yields with the chisel plow treatment were low in the middle phase, but high for the end phase of the study; soybean yields with the ridge-till treatment were high in the middle phase, but low in the end phase.

Soybean yields in the moldboard plow and chisel plow treatments were higher than no-till in 2 of 4 years (Singer et al., 2004). No yield differences were observed due to tillage system in the other two years. Compost was also applied to soybeans and increased yields in 3 of 4 years.

Averaged over eight years, soybean yields were not significantly affected by no-till, reduced tillage, or conventional tillage in Iowa (Brown et al., 1989). In two of the years plant densities in no-till were higher than reduced tillage and conventional tillage, but no-till plant densities were lower than reduced tillage and conventional tillage in two other years. In 1983, no-till soybeans yielded less than reduced tillage and conventional tillage, but this result was not observed in any other years.

Row Spacing

Row spacing is an important factor in achieving optimal soybean yield. An earlier study suggested that soybeans in narrow rows have higher incidence and severity of Sclerotinia stem rot because of more disease pressure under the canopy due to less ari movement and higher humidity (Grau and Radke, 1984). Having more space between plants in the row in narrow rows results in better canopy development and better light interception earlier in the growing season, which can be positive for yield (De Bruin and Pedersen, 2008). At three locations in Iowa, soybeans in 38-cm rows yielded 248 kg ha^{-1} more than those in 76-cm rows, and this was consistent among environments. Per 100 seeds planted, more plants survived until harvest in 38-cm rows than in 76-cm rows.

In New York in a Honeoye silt loam that has been in corn-soybean rotation since 1990, drilled soybeans in 19-cm rows yielded 7% more than those in 38-cm rows planted with a split-row planter and 17% more than those in 76-cm rows; soybean yields in 38-cm rows were 8% higher than those in 76-cm rows (Cox and Cherney, 2011). Plant density was determined at V3, and no differences were observed among row spacings. Drilled soybeans in 19-cm rows with a seeding rate of 420,000 seeds ha^{-1} had the highest yields of 3.53 Mg ha^{-1}.

Zhou et al. (2011) established that soybean yields were highest in row spacings less than or equal to 27 cm in northern China on a silt loam. With wider rows, there was more competition between plants, and plants were closer together which resulted in resources being wasted. With narrower rows, the plants achieved more equidistant spacing which resulted in less competition, better yield components, and higher yields.

Both irrigated and nonirrigated 25-cm row soybeans in Iowa yielded more than those in 100-cm rows, even though soybeans in 100-cm rows produced more biomass than those in 25-cm rows (Taylor et al., 1982). The narrow rows had greater light interception toward the end of the pod filling phase, which is likely the reason for the yield advantage in narrow rows.

Tillage and Row Spacing

As previously mentioned, narrower row spacings have yields that are at least equal to if not greater than yields in wider rows. Additionally, tillage can affect soybean yields, but results are not always consistent. Narrow rows may have a yield advantage in some, but not all, tillage systems.

In a Plano silt loam, soybeans grown in a no-tillage system yielded 200 kg ha^{-1} more than those in a conventional tillage system (Pedersen and Lauer, 2003). The authors note that this yield difference could be due to an infestation of SCN but need to do more work to confirm this. Although some yield differences were seen between row spacings when the years were examined individually, averaged over the years of the study, no yield differences were observed between the row spacings.

At three Minnesota locations over three years, soybean yields in a till-plant tillage system had yields 114 kg ha^{-1} lower than those in the moldboard plow system (Lueschen et al., 1992). Soybean population was also affected by tillage. Depending on location, no-till, till-plant, and spring-disk tillage treatments had the lowest populations. Averaged over all years, soybeans in 25-cm rows at Morris yielded 343 kg ha^{-1} more than those in 76-cm rows, 222 kg ha^{-1} more than those in 76-cm rows at Lamberton, and 229 kg ha^{-1} more than those in 76-cm rows at Waseca. Tillage did not change the soybean yield response to row spacing.

Fungicide/Insecticide

At two Iowa locations during 2005 and 2006, the effectiveness of a preventative fungicide treatment was tested. Four cultivars of glyphosate resistant soybeans were tested along with nine fungicide treatments (pyraclostrobin, tebuconazole, and pyraclostrobin + tebuconazole all applied at R1, R3, or R5) and an untreated control. All plots had a row spacing of 38 cm and were tilled by chisel plowing in the fall and field cultivation twice in the spring. When comparing soybean yields from the fungicide treatments to the control, there were no differences. In terms of plant height, there were some differences between treatments, but none were different than the control (Swoboda and Pedersen, 2009).

In Indiana, soybean seed yield increased with application of pyraclostrobin and lambda-cyhalothrin (Henry et al., 2011). Pyraclostrobin applied at R2 followed by lambda-cyhalothrin applied at R4, a tank mixture of glyphosate and pyraclostrobin applied at R2 followed by lambda-cyhalothrin at R4, and a tank mixture of pyraclostrobin and lambda-cyhalothrin applied at R4 yielded 304 kg ha^{-1}, 220 kg ha^{-1}, and 237 kg ha^{-1}, respectively, more than the control of soybeans receiving only herbicide treatments. The heaviest seeds occurred in soybeans with both pyraclostrobin and lambda-cyhalothrin applied. A single application of lambda-cyhalothrin at R4 did not increase seed mass, which suggests that the increases in seed mass were because of the fungicide treatment.

Soybeans without sub-surface drainage yielded 600 to 810 kg ha^{-1} more when pyraclostrobin was applied compared to the untreated soybeans (Nelson and Meinhardt, 2011). Soybean yields were not increased by fungicide treatments within the drainage only system or the drainage plus subirrigation system, but when compared to the nondrained and nontreated control, yields increased with fungicide application from 670 kg ha^{-1} to 1,070 kg ha^{-1}.

Based on the literature, I hypothesize a yield increase when corn residue remains on the soil surface and lower yields when corn residue is removed, little yield difference with tillage treatments, higher yields with narrow rows, and little yield response to fungicide/insecticide treatment.

Soybean Nodulation

Legumes, such as soybeans, have a symbiotic relationship with rhizobium, which results in fixing N_2. The rhizobuim infects a root hair which allows bacteria to move into the cortex cells of the root. The nodule starts to grow and expand as the cortex cells divide. As a part of the symbiotic relationship, the bacteria get a favorable, anaerobic living environment with sugar, water, and minerals, while the plant receives fixed N_2 from the bacteria in the nodule. Nodules without the pink color inside are most likely a result of an ineffective rhizobium strain and lack leghemoglobin so do not provide N_2 to the plant (Gardner et al., 1985)

Histosols with low pH resulted in low nodule counts, large nodules, and primary root nodulation (Mengel and Kamprath, 1978). Histosols with a higher pH because of added lime resulted in high nodule numbers, decreased nodule weight, and nodulation on lateral roots. Eight soils were tested and five rates of limestone were added to the soils. Pots without lime application had an average of 2 nodules per pot, while those with the maximum lime rate had an average of 114 nodules per pot.

In a Haplic Luvisol in Poland, soil compaction and straw mulching affected nodule measurements and numbers (Siczek and Lipiec, 2011). Three compaction treatments were used: non-compacted, moderately compacted, and strongly compacted. Mulch treatments were either mulched or unmulched. With increased compaction came an increase in the number of nodules with diameters of 0.41-0.60 and >0.61 cm and a decrease in the number of nodules in the groups <0.20 and 0.21-0.40 cm. Mulching also increased the number of nodules sized 0.41-0.60 cm and decreased the number sized 0.21-0.40 cm. When the soil was unmulched, the number of nodules plant^{-1} was highest in the moderately compacted soil than in the non-compacted and strongly compacted soils. When the soil was mulched, the number of nodules plant^{-1} was highest in the strongly compacted soil, lowest in the non-compacted soil, and intermediate in the moderately compacted soils.

Tillage had little effect on nodulation and acetylene reduction in a Webster clay loam with corn as the previous crop (Lindemann et al., 1982). Five tillage treatments were used: no tillage; fall moldboard plow, field cultivate, and disk; spring moldboard plow, field cultivate, and disk; fall chisel plow and disk; spring chisel plow and disk; and disk twice. Although some differences were seen at specific sampling times or in specific years, tillage had little effect on nodulation and acetylene reduction overall.

Some management practices affect soybean nodulation. Soil acidity and rhizobium strains impact soybean nodulation. Soils with a low pH resulted nodulation on the taproot of the soybean, whereas soils with a high pH resulted in more nodulation on the lateral roots (Mengel and Kamprath, 1978). There is no evidence that tillage makes nodulation a limiting factor (Lindemann et al., 1982). While some work has been conducted on how cultural practices affect soybean nodulation, corn residue management, tillage, and their interaction in affecting nodulation has not been examined. Based on the literature, I hypothesize little difference in number of nodules plant^{-1} due to tillage and corn residue treatments.

MATERIALS AND METHODS

Trials were conducted at three University of Illinois Crop Sciences research centers: at Urbana in east-central Illinois (40.0609 N, 88.2264 W); Brownstown in south-central Illinois (38.9492 N, 88.9598 W); and at Dixon Springs in southern Illinois (37.4368 N, 88.6674 W) – in 2012 and 2013. Soybean followed corn in all cases. Soil types were: Drummer silty clay loam (fine-silty, mixed, superactive, mesic Typic Endoaquolls) and Elburn silt loam (Fine-silty, mixed, superactive, mesic Aquic Argiudolls) at Urbana; Cisne silt loam (fine, smectitic, mesic, Mollic Albaqualfs) at Brownstown; and Belknap silt loam (coarse-silty, mixed, active, mesic Fluventic Endoaquepts) at Dixon Springs..

This study was designed as a randomized complete block with four replications and four factors. Previous crop was corn, and there were three corn residue treatments: 1) standing (undisturbed); 2) chopped and left in the field; and 3) chopped and removed from the field. Tillage treatments were no-tillage and conventional tillage with a chisel plow. All trials were in fields in which previous crops were produced using tillage. Planting occurred in either 38- or 76-cm rows. Fungicide/insecticide treatment had two levels: applied at R3 and an untreated check.

At Urbana, the study was designed as a split-split-split-plot. Corn residue treatments were assigned to main plots. A rotary mower was used to chop residue in the fall after corn harvest for the chopped residue treatment and residue was removed by raking it into a windrow after chopping and removing it from the field for the removed residue treatment. No-till and conventional tillage were assigned to subplots. Conventional tillage consisted of a chisel plow in the fall following corn harvest and a soil finisher used twice before planting. Row spacings were assigned to sub-subplots, and were planted using the same split-row John Deere planter. Foliar fungicide/insecticide treatment and untreated checks were assigned to sub-sub-subplots at Urbana. The fungicide/insecticide treatment was applied at R3 with a backpack sprayer using pyraclostrobin at 439 mL ha^{-1} (110 g ai ha^{-1}) and lambda-cyhalothrin at 140 mL ha^{-1} (35 g ai ha^{-1}). Application occurred on July 11, 2012 and August 1, 2013.

At Urbana, the cultivar Pioneer 93Y40 was planted in both years. In 2012, the seeding rate was 395,000 plants ha^{-1} and in 2013, the seeding rate was 371,000 plants ha^{-1}; both rates are within the optimal range. Soybeans were planted on May 10, 2012 and June 6, 2013. Plots were 3 m wide and 11 m long. Herbicides were applied as needed at recommended rates. Early stand counts were taken within an area of 1 m^2 in each sub-sub-sub plot at growth stage V1 in 2013 and at stage R8 prior to harvest in both years. At R8 prior to harvest, plant heights were measured to the top of the stem. Harvest of a 1.5 m x 11 m area was done using an Almaco plot combine. Harvest occurred on October 12, 2012 and October 25, 2013. Yields were adjusted to 130 g kg^{-1} grain moisture basis.

At Brownstown and Dixon Springs, the study was designed as a split-plot experiment. Tillage-row spacing combinations comprised main plots. For the conventional tillage treatment, a chisel plow was used in the fall followed by a soil finisher used twice before planting. A split-row John Deere planter was used for planting.

Corn residue treatments as described above were assigned to sub-plots in combination with fungicide treatment at these sites. Residue treatments were accomplished in the spring for the 2012 growing season, and in the fall of 2012 for the 2013 crop. Corn residue was chopped with a stalk chopper and hand-raked from those plots residue removal. Fungicide was not applied at either site in 2012 or at Brownstown in 2013. In 2013, fungicide was applied at R3 at Dixon Springs as pyraclostrobin at a rate of 439 mL ha^{-1} (110 g ai ha^{-1}) on July 29 using a backpack sprayer.

The cultivar Pioneer 94Y80 was planted at both sites in both years using a seeding rate of 371,000 ha^{-1} in 2012 and 445,000 ha^{-1} in 2013; both rates are within the optimum range. At Brownstown, soybeans were planted on May 17, 2012 and July 9, 2013, following wet spring weather. At Dixon Springs, following delays due to wet weather, soybeans were planted on June 4, 2012 and June 5, 2013. Plots were 3 m wide and 11 m long at Brownstown and 12 m long at Dixon Springs. Herbicides were applied as needed at each location at recommended rates. Harvest occurred on October 22, 2012 at Brownstown; the trial at Brownstown was abandoned in 2013 due to very late planning and poor growth. At Dixon Springs, trials were harvested on October 24, 2012 and October 24, 2013. Harvest of a 1.5 m x 11 m area at both sites was done using an Almaco plot combine, with yields adjusted to 130 g kg^{-1} moisture.

In 2013 at the Urbana site, root samples were collected at growth stage R6 for nodule counts. Six plants per plot were collected using a spade to a depth of 15 cm in subplots (residue and tillage treatments) in 76-cm rows without fungicide/insecticide. The shoot was removed from the root mass, excess soil was carefully removed from the root, and care was taken to collect any roots that broke off of the root mass.

Statistical analysis was performed using the Mixed procedure of Statistical Analysis System (SAS) software (SAS, 2010). Years were treated as random at all locations to be able to apply results to a wide range of conditions. Because of the large weather differences between the two years, data at Urbana were also analyzed taking years as fixed. Locations were treated as random; and corn residue, tillage, row spacing, and fungicide/insecticide treatments were treated as fixed. Fungicide/insecticide treatment was not included in the plant density analysis at Urbana. A p-value of 0.10 was used to test effects of treatment means.

RESULTS AND DISCUSSION

In 2012, unusually hot and dry conditions prevailed into August, followed by above normal rainfall in August and September (Table 1). May 2012 temperatures were 3.6 °C higher at Urbana, 2.5 °C higher at Brownstown, and 2.3 °C higher at Dixon Springs compared to 30-year means. June temperatures did deviate greatly from normal, but July had temperatures above 30-year means. Compared to the 30-year normal monthly precipitation, precipitation was 104 mm lower in Urbana, 100 mm lower in Brownstown, but only 2 mm lower in Dixon Springs in July 2012. In 2012, Brownstown yields were 803 kg ha^{-1} higher than Dixon Springs yields. This yield difference was likely due to difference in seasonal precipitation: Brownstown received 554 mm of rain from May to September while Dixon Springs received only 338 mm. Additionally, Dixon Springs was planted 3 weeks later than Brownstown.

In 2013, a cool and wet spring resulted in late planting, and abundant rainfall in June and July gave way to below-normal rainfall in August and September, especially at Urbana and Brownstown. Temperatures in 2013 were generally at or below normal. In June 2013, precipitation was 49 mm above normal at Urbana and 39 mm above normal at Dixon Springs. In 2013, Urbana yields were 507 kg ha^{-1} higher than Dixon Springs yields, even though Dixon Springs had abundant rainfall through July and August.

Table 1. Growing season air temperatures and monthly precipitation totals for 2012-2013 at Urbana, Brownstown, and Dixon Springs, IL. Numbers in parentheses are departures from 30-year normal (Water and Atmospheric Resources Monitoring Program).

	Urbana				Brownstown				Dixon Springs			
	2012		2013		2012		2013		2012		2013	
Temperature	°C											
May	20.5	(3.6)	18.1	(1.2)	21.1	(2.5)	18.7	(0.1)	21.8	(2.3)	19.7	(0.2)
June	22.7	(0.4)	21.8	(-0.5)	23.0	(-0.9)	22.1	(-1.8)	23.5	(-0.4)	23.1	(-0.8)
July	27.6	(3.8)	22.8	(-1.0)	28.2	(2.9)	22.6	(-2.7)	27.7	(1.8)	22.8	(-3.1)
August	23.1	(0.1)	22.9	(-0.1)	23.4	(-0.7)	22.9	(-1.2)	24.6	(-0.8)	23.4	(-2.0)
September	17.8	(-1.2)	20.6	(1.6)	18.2	(-1.8)	26.4	(6.4)	19.3	(-2.2)	21.2	(-0.3)
Precipitation	mm											
May	79	(-45)	95	(-29)	113	(-25)	225	(87)	16	(-125)	121	(-20)
June	58	(-52)	159	(49)	25	(-80)	91	(-14)	30	(-73)	142	(39)
July	15	(-104)	90	(-29)	1	(-100)	132	(31)	96	(-2)	115	(17)
August	141	(41)	9	(-91)	227	(151)	54	(-22)	68	(-16)	172	(88)
September	145	(65)	17	(-63)	188	(107)	26	(-55)	129	(39)	48	(-42)

Urbana

Corn residue management did not significantly affect soybean yields, but tillage and row spacing affected yields across years with years as random, across years with years as fixed, and by year (Table 2). In 2012, soybeans with no-tillage yielded 270 kg ha^{-1} less than those with tillage. Results were similar in 2013, where no-till soybean grain yields were 115 kg ha^{-1} less with tillage (Table 3). Averaged over 2012 and 2013, yield with tillage was 5.4% more than under no-till. These results are similar to the findings of West et al. (1996) where no-till soybeans yielded 8% less than tilled soybeans. Yield in 38-cm rows was 114 kg ha^{-1} higher than in 76-cm rows in 2012, and 231 kg ha^{-1} higher in 2013 (Table 3); 38-cm rows yielded 5.2% more than 76-cm rows. This supports the hypothesis that narrow rows would yield more than wide rows.

Table 2. Corn residue, tillage, row spacing, and fungicide influences on soybean grain yields for 2012 and 2013 in Urbana, IL.

Source	df	2012		2013		2012-13 Year random		2012-13 Year fixed		x Year	
		Pr > F									
Year	1	–		–		–		0.002	**	–	
Corn Residue (Res)	2	0.642		0.597		0.337		0.393		0.975	
Tillage (Till)	1	0.061	*	0.028	**	0.006	***	0.008	***	0.249	
Res x Till	2	0.481		0.283		0.228		0.246		0.732	
Row Spacing (Row)	1	0.036	**	0.000	***	0.000	***	0.000	***	0.107	
Res x Row	2	0.682		0.854		0.891		0.877		0.678	
Till x Row	1	0.345		0.014	**	0.348		0.320		0.022	**
Res x Till x Row	2	0.088	*	0.059	*	0.030	**	0.021	**	0.336	
Fungicide/Insecticide (F/I)	1	0.855		0.068	*	0.351		0.357		0.224	
Res x F/I	2	0.996		0.440		0.773		0.778		0.740	
Till x F/I	1	0.984		0.556		0.719		0.722		0.748	
Res x Till x F/I	2	0.278		0.122		0.198		0.207		0.202	
Row x F/I	1	0.364		0.222		0.965		0.965		0.147	
Res x Row x F/I	2	0.945		0.889		0.857		0.860		0.998	
Till x Row x F/I	1	0.243		0.708		0.232		0.238		0.451	
Res x Till x Row x F/I	2	0.548		0.720		0.859		0.862		0.414	

*Significant at the 0.10 probability level
**Significant at the 0.05 probability level
***Significant at the 0.01 probability level

Table 3. Soybean grain yield means at Urbana, IL for 2012 and 2013. Means for 2012-13 were separated with years considered random.

Source	2012		2013		2012-13	
	kg ha^{-1}					
Year						
2012	–		–		2,944	b
2013	–		–		3,935	a
Corn Residue						
Standing	2,797		3,802		3,300	
Chopped	3,054		4,079		3,567	
Removed	2,980		3,923		3,451	
Tillage						
No-Till	2,809	b	3,877	b	3,343	b
Tilled	3,079	a	3,992	a	3,535	a
Row Spacing						
38 cm	3,001	a	4,050	a	3,525	a
76 cm	2,887	b	3,819	b	3,352	b
Fungicide/Insecticide						
+F/I	2,938		3,975	a	3,456	
-F/I	2,949		3,895	b	3,422	

Different letters within columns and treatment factors indicate differences at p=0.10.

The fungicide/insecticide treatment did not affect yields in 2012 or when averaged across years, but increased yield by 80 kg ha^{-1} in 2013 (Table 3). Reduced stomatal conductance resulting from strobilurin fungicide application (Nason et al., 2007) might have helped plants retain water, especially in this study, where the weather following fungicide application was drier in 2013 than in 2012.

The residue x tillage x row spacing interaction was consistent across years (Table 2). Chopping residue but leaving it in the field, tilling, and planting in 38-cm rows produced a yield of 3,791 kg ha^{-1}, while standing residue, no-tillage, and 76-cm rows yielded only 3,059 kg ha^{-1}, or 19.3% less (Fig. 1).

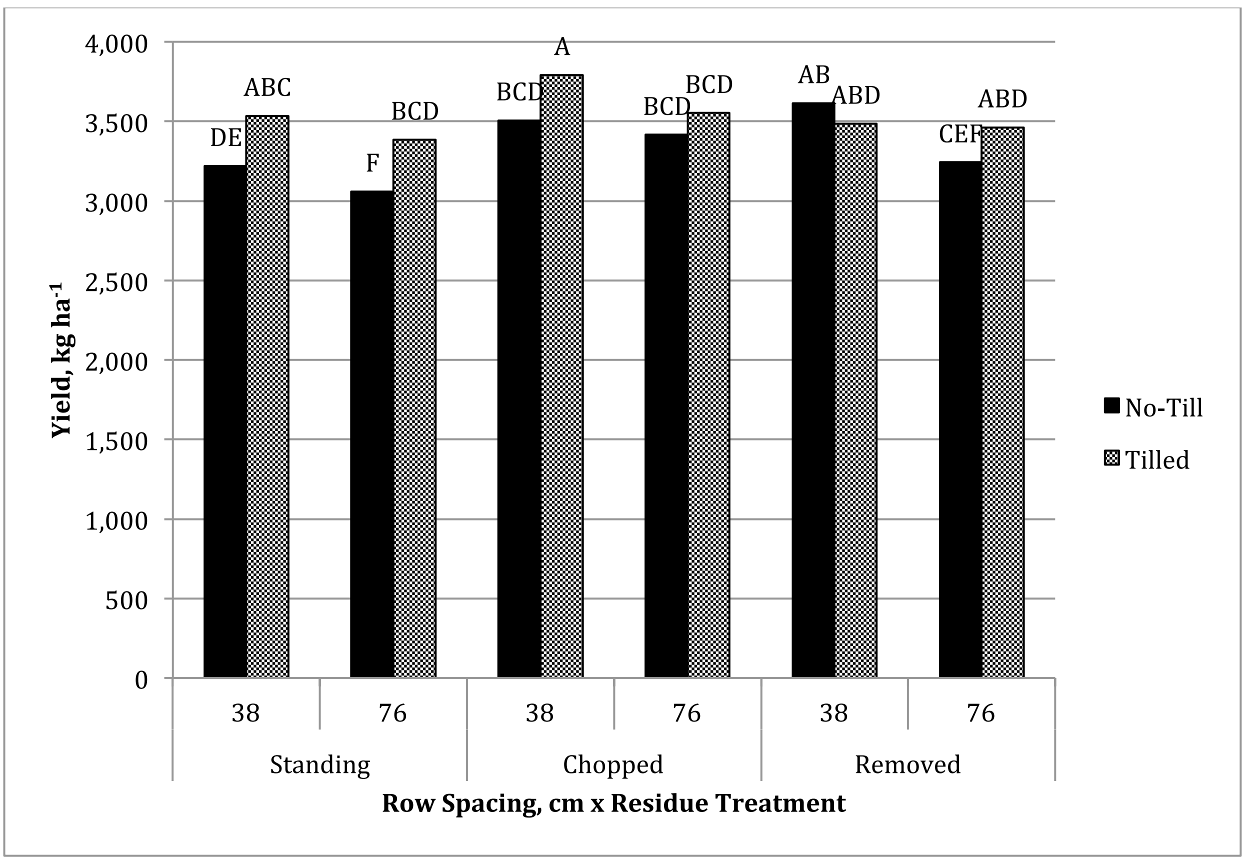

Figure 1. Soybean grain yields for residue, tillage, and row spacing treatments at Urbana. Data are averaged over fungicide/insecticide treatments and two years.

In all standing residue treatments, soybeans without tillage yielded less than those with tillage. In 38-cm rows with residue left standing, no-till soybeans yielded 315 kg ha^{-1} less than those with tillage. Similarly, in 76-cm rows with residue left standing, no-till soybeans yielded 326 kg ha^{-1} less than tilled. When residue was chopped and remained on the plot and soybeans were planted in 38-cm rows, no-till soybeans yielded 285 kg ha^{-1} less than those in tillage. On the other hand, there were no differences in yields between tilled and no-till in 76-cm rows with chopped corn residue. When residue was removed, there was no difference in tillage treatments in 38-cm rows, but in 76-cm rows, no-till soybeans yielded 220 kg ha^{-1} less than those in tillage (Fig. 1). The three-way interaction stemmed from the fact that soybeans responded similarly to tillage and row spacing when corn residue was left standing and when it was chopped and left on the field, but they responded differently to tillage and row spacing when corn residue was chopped and removed from the field. This is likely due to the lower water availability when residue is removed from the soil surface (Doran et al., 1984; van Donk et al., 2012;).

In addition to analyzing soybean yields with year considered random, yields were also analyzed with year considered fixed. As discussed above, 2012 and 2013 had different weather patterns; this could have resulted in different yield responses to treatments depending on the year. Despite the fact that soybean yields in 2012 averaged 991 kg ha^{-1} (25.2 %) lower than in 2013, the only significant interaction involving years at Urbana was the year x tillage x row spacing interaction (Table 2). In 2012, there were no differences between row spacings within each tillage treatment, but in 2013 in no-till, 38-cm rows yielded 351 kg ha^{-1} more than 76-cm rows (Fig. 2). The cool and wet spring of 2013 may have been more of an advantage to soybeans planted in 38-cm rows than in 76-cm rows in no-till.

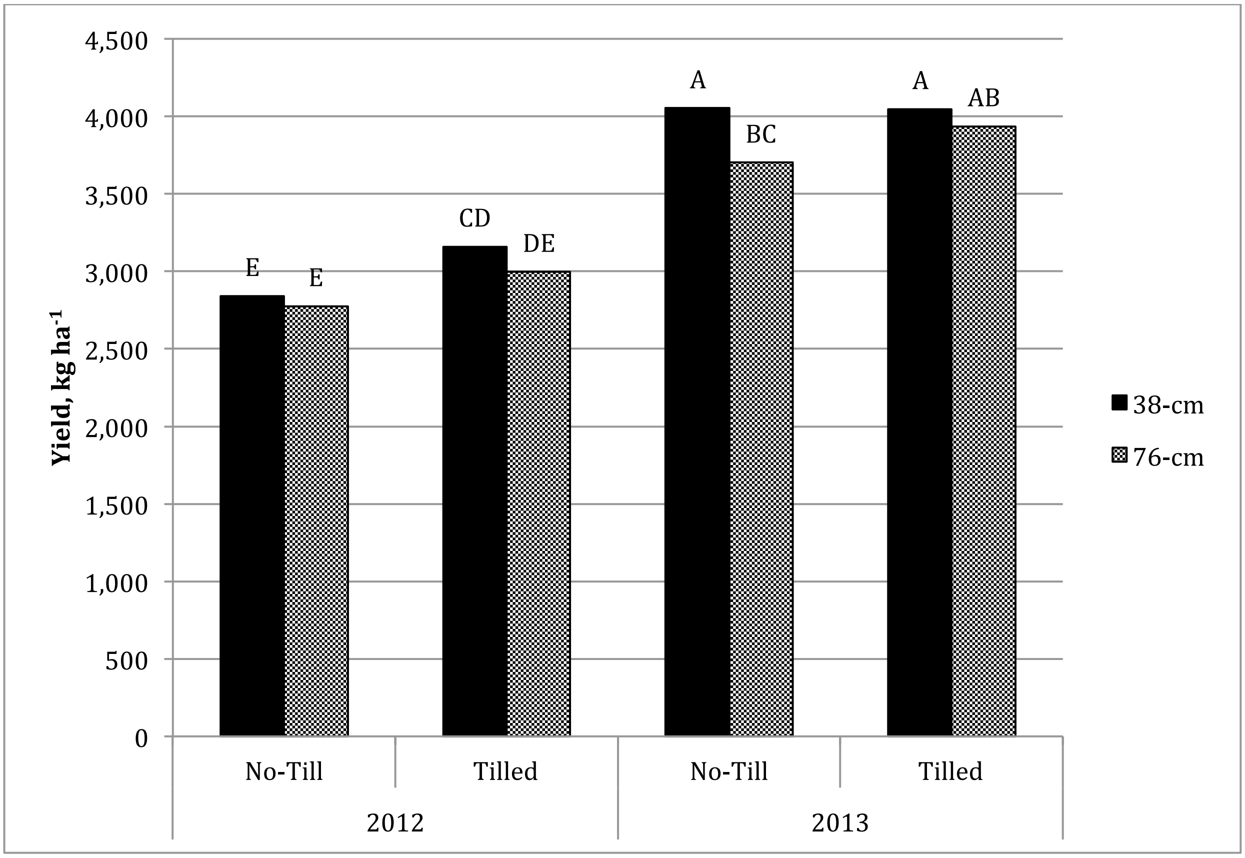

Figure 2. Soybean grain yield for year, tillage, and row spacing treatments at Urbana. Data are averaged over fungicide/insecticide treatments and residue treatments with year considered fixed.

The tillage x row spacing interaction had a significant effect on soybean density: 38-cm rows had 20,400 plants ha^{-1} more in tilled than in the no-till plots, while in 76-cm rows, tilled plots had 16,400 plants ha^{-1} fewer than the no-till plots (Fig. 3). It is surprising that no-till plots did not have consistently lower density than the tilled plots, because the tractor tires drive over 2 of the 7 rows in 38-cm rows during planting, but drives in between the rows 76-cm rows. Similarly, in a corn-soybean rotation, no-till soybean density was 11.6% lower than plowed soybean density (West et al., 1996).

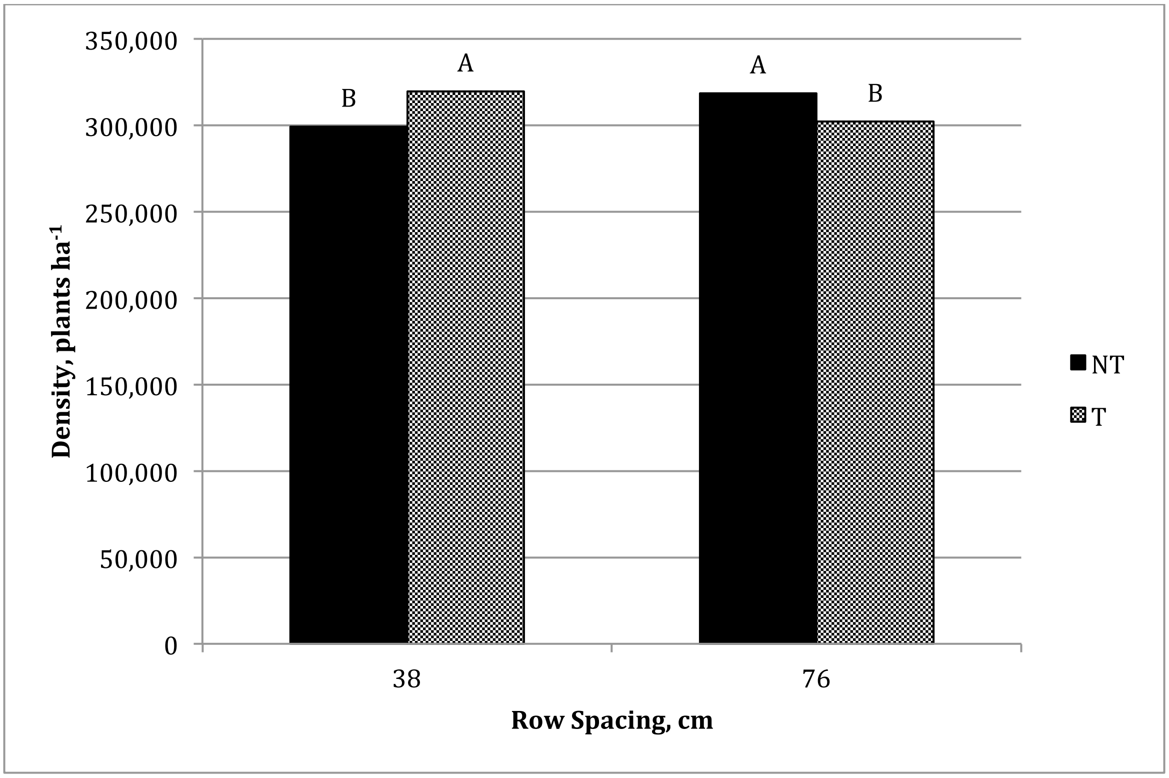

Figure 3. Soybean density for row spacing and tillage treatments in Urbana. Data are averaged over residue treatments and two years, with years considered as random.

Row spacing affected the difference between the early and late stand counts in 2013: 76-cm rows had 14,000 plants ha^{-1} more plants at V1 than at R8, while 38-cm rows showed that the V1 stand count was only 7,000 plants ha^{-1} more than the R8 stand count. Increased within-row competition may well have been responsible for greater stand loss in wide rows. A similar result occurred in Iowa where 38-cm rows had greater soybean establishment than 76-cm rows (De Bruin and Pedersen, 2008). This points to a lower risk of stand loss in narrow rows.

Tillage and row spacing affected mature plant height, but residue and fungicide/insecticide treatment did not. Soybeans were 3 cm taller with tillage than with no-till and were 3.5 cm taller in 76-cm rows than in 38-cm rows (Table 4). Tilled soybeans also yielded more than no-till (Table 3); tilled soybeans may have been more able to access water, whereas those in no-till had more restricted roots. Even though soybeans in 38-cm rows were shorter than those in 76-cm rows, they did not have lower yields; the opposite was true – the taller soybeans in 76-cm rows had lower yields. This is contrary to Zhou et al. (2011) and Cox and Cherney (2011) – both reported that narrow rows had taller soybeans than wide rows. Overall, there was no correlation between soybean height and yield in row spacing and tillage treatments (Fig. 4).

Table 4. Corn residue, tillage, row spacing, and fungicide/insecticide effects on soybean density plant height at maturity at Urbana in 2012 and 2013 with year considered random. Fungicide/insecticide was not included in density analysis.

Source	Density plants ha^{-1}	Height cm	
Corn Residue			
Standing	309,000	78.3	
Chopped	307,000	81.3	
Removed	313,000	82.3	
Tillage			
No-Till	309,000	79.2	b
Tilled	311,000	82.0	a
Row Spacing			
38 cm	309,000	78.8	b
76 cm	310,000	82.4	a
Fungicide/Insecticide			
+ F/I	-	81.1	
- F/I	-	80.1	

Different letters within treatment factors indicate yield differences at p=0.10.

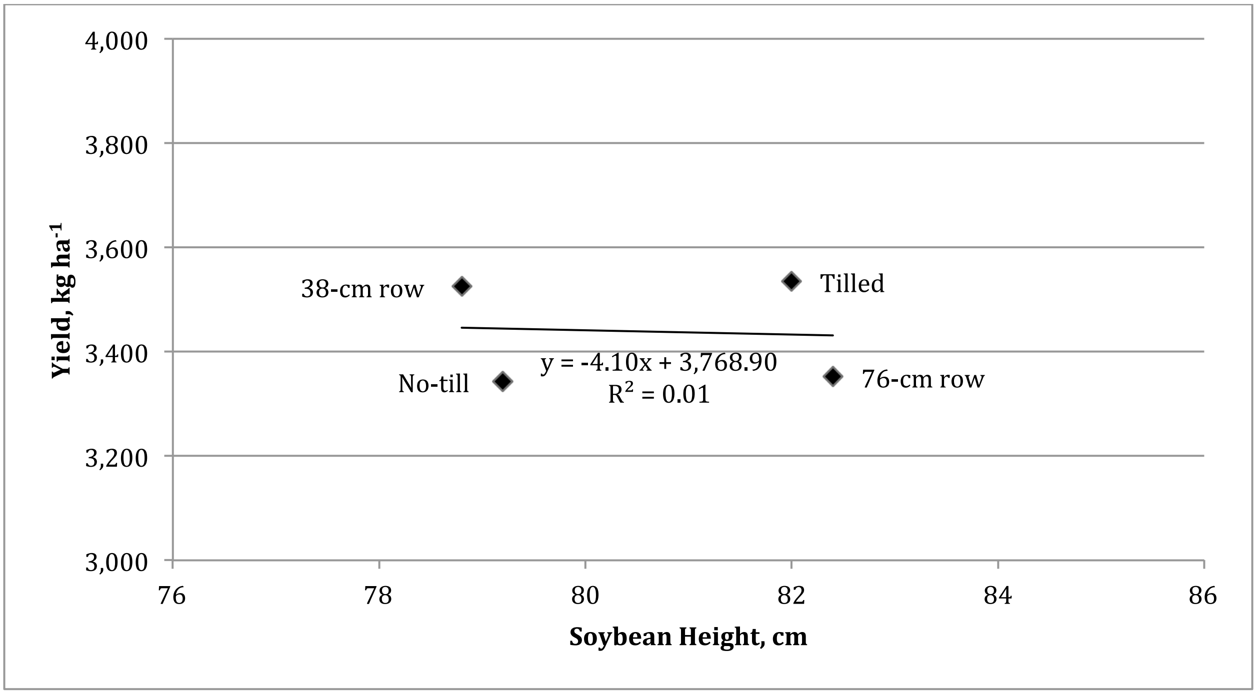

Figure 4. Linear relationship of soybean grain yield to mature soybean height for two years at Urbana, IL.

Dixon Springs and Brownstown

In 2012 at Dixon Springs, corn residue, tillage, and row spacing did not affect yields (Table 5), but in 2012 at Brownstown, removing residue resulted in yields 199 kg ha^{-1} lower than the standing residue treatment, while soybean yields with corn residue removed were not different than yields in the chopped residue treatment (Table 6). At Dixon Springs in 2013, soybeans in 38-cm rows produced 448 kg ha^{-1} (14 %) more yield than in 76-cm rows. This is similar to the narrow-row response reported by DeBruin and Pedersen (2008), Cox and Cherney (2011), and Zhou et al. (2011), but is larger than expected for southern Illinois. The significant tillage x fungicide effect at Dixon Springs in 2013 (Table 5) resulted from failure of yield to respond to fungicide in no-till, but an increase of 256 kg ha^{-1} from fungicide with tillage (Fig. 5). This interaction is unexpected and is possibly due to disease control.

Table 5. Tillage, row spacing, and corn residue influences on soybean grain yields for 2012 and 2013 in Brownstown and Dixon Springs, IL. Year and location were considered as random. Fungicide results were not included from Dixon Springs 2013.

		Brownstown		Dixon Springs			Brownstown and Dixon Springs
Source	**df**	**2012**		**2012**	**2013**		**2012-13**
		Pr > F					
Tillage (Till)	1	0.326		0.206	0.976		0.929
Row Spacing (Row)	1	0.182		0.131	0.002	***	0.527
Till x Row	1	0.735		0.676	0.750		0.774
Corn Residue (Res)	2	0.093	*	0.450	0.939		0.935
Till x Res	2	0.836		0.954	0.536		0.646
Row x Res	2	0.256		0.827	0.946		0.787
Till x Row x Res	2	0.409		0.359	0.839		0.159

*Significant at the 0.10 probability level
**Significant at the 0.05 probability level
***Significant at the 0.01 probability level

Table 6. Soybean grain yield means at Brownstown and Dixon Springs for 2012 and 2013. Year and location were considered as random.

	Brownstown		Dixon Springs			Brownstown and Dixon Springs
	2012		**2012**	**2013**		**2012-13**
	kg ha^{-1}					
Tillage						
No-Till	3,448		2,612	3,430		3,178
Tilled	3,551		2,789	3,427		3,194
Row Spacing						
38 cm	3,428		2,808	3,652	a	3,257
76 cm	3,572		2,592	3,204	b	3,116
Corn Residue						
Standing	3,594	a	2,643	3,419		3,201
Chopped	3,511	ab	2,685	3,420		3,172
Removed	3,395	b	2,767	3,445		3,185

Different letters within treatment factors indicate yield differences at p=0.10.

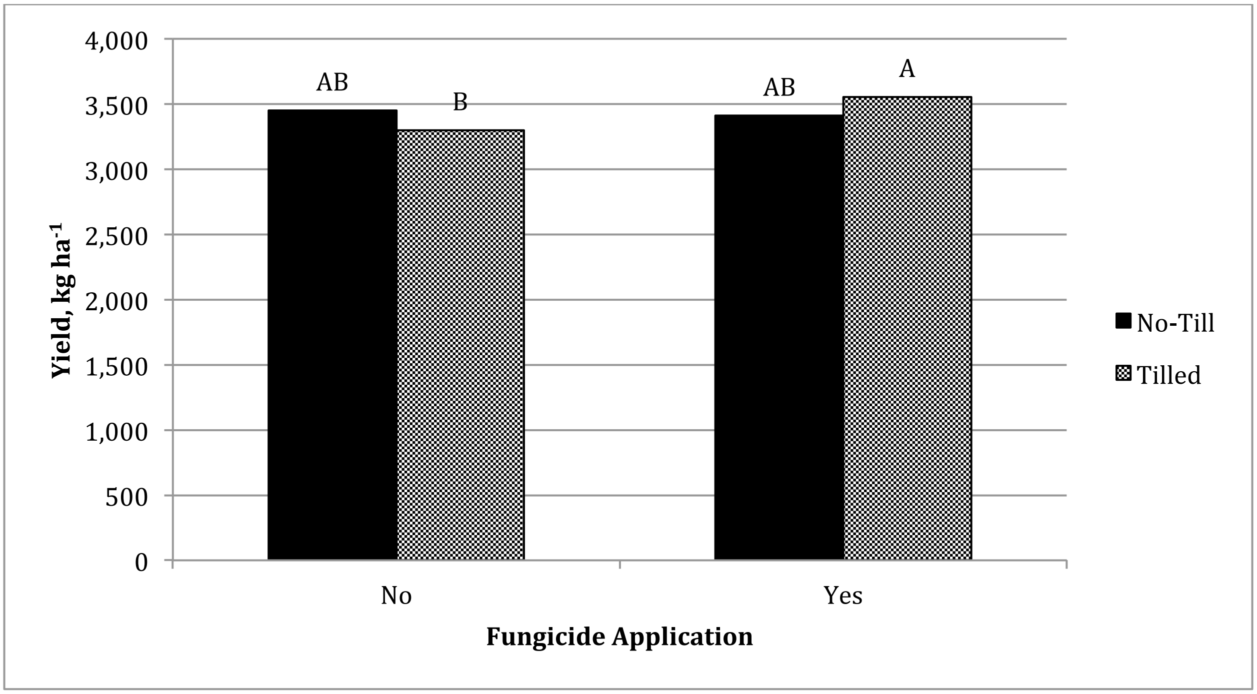

Figure 5. Foliar fungicide and tillage effects on soybean grain yield at Dixon Springs in 2013. Data are averaged over residue and row spacing treatments.

Data for Brownstown 2012 and Dixon Springs 2012-2013 were analyzed together, excluding data from fungicide-treated plots at Dixons Springs in 2013. Year, location, and block were treated as random terms. Across the three southern Illinois sites, none of the fixed effects or their interactions resulted in significant yield differences (Table 5).

Nodule counts

At the R6 growth stage at Urbana in 2013, soybean plants growing in standing residue had 11 more nodules plant^{-1} than did those with residue chopped, and 7 more nodules plant^{-1} than where residue was removed; nodule counts in the chopped and removed residue treatments were not different (Table 7). It is not clear why standing corn residue would increase nodule numbers, but perhaps some lowering of water loss rates due to the physical presence of standing residue early in the season might have enabled more nodules to survive. These differences in nodule counts were unrelated to yield differences among residue treatments at Urbana 2013 (Table 3).

Table 7. Corn residue and tillage influences on soybean root nodule counts for 2013 at R6 in Urbana and soybean root nodule count means.

	R6	
	Nodules Plant^{-1}	Pr > F
Residue		0.026**
Standing	57 a	
Chopped	47 b	
Removed	51 b	
Tillage		0.540
No-Till	53	
Tilled	50	
Residue x Tillage		0.590

*Significant at the 0.10 probability level
**Significant at the 0.05 probability level
Different letters within treatment factors indicate yield differences at P=0.10.

SUMMARY AND CONCLUSIONS

Corn residue management, tillage, and row spacing did not consistently affect soybean yields across years and locations. At Urbana 2012-13 and Dixon Springs in 2013, soybeans in 38-cm rows yielded more than those in 76-cm rows. This result confirms the general consensus in the literature that narrower rows yield as much as, or more than, wider rows (De Bruin and Pedersen, 2008; Cox and Cherney, 2011; and Zhou et al., 2011).

In Urbana, the northernmost environment with more productive soils, corn residue treatment did not affect yields. Soybeans with tillage yielded 5.7% more than those in no-till. Soybeans in 38-cm rows yielded 5.2% more than those in 76-cm rows. The residue x tillage x row spacing interaction revealed that yield responses to tillage and row spacing were similar in standing and chopped residue treatments, but responses were different when residue was removed. The effect of residue treatment is dependent on both row spacing and tillage treatment to produce the highest soybean yields.

Across the three southern Illinois environments with less productive soils, residue, tillage, and row spacing failed to produce significant yield responses. At Brownstown in 2012, standing residue may have helped hold in some soil moisture and thus yield 5.9% more than the removed residue treatment. At Dixon Springs in 2013, 38-cm rows yielded 14.0% more than 76-cm rows. With tillage, fungicide produced a yield increase of 256 kg ha^{-1}, while there were no differences in no-till at Dixon Springs 2013.

These results indicate that tillage can increase yields in a location with more productive soils but may not affect yields in environments with less productive soils. In more northern environments in Illinois, corn residue management impacts soybean yields depending on tillage system and row spacing. In southern Illinois, standing residue helped increase yields at one location and did not result in decreased yields across the other years and locations. Removing residue can hurt yields, as occurred in Brownstown in 2012. In the northern Illinois environments, planting soybeans into standing corn residue did not show decreased soybean yields overall. These results do not indicate that planting soybeans into standing corn residue hurts yields, and suggest that removing residue can lower yields.

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